RUNWAY INCURSION PREVENTION SYSTEM CONCEPT VERIFICATION: GROUND SYSTEMS AND STIS-B LINK ANALYSIS

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Introduction

Runway incursions continue to make headlines, and reduction of incursions continues to be a top priority for the Federal Aviation Administration (FAA), the National Transportation Safety Board (NTSB), and the National Aeronautics and Space Administration (NASA) [1, 2]. Recent programs, such as the FAA's Runway Incursion Reduction Program (RIRP), and NASA's Runway Incursion Prevention System (RIPS) have placed newly developed airport surveillance systems and technology at Dallas-Fort Worth (DFW) International airport for testing in an attempt to develop systems that will reduce the risk of runway incursions.

The primary objective of the RIPS test conducted in October 2000 at DFW was to assess and validate the performance of communication, navigation and surveillance (CNS) infrastructure technologies and incursion alerting systems for preventing runway incursion. This overall objective included the following segments:

- Assessment of the performance of the airport surface infrastructure (data linked Surface Traffic Information Systems-Broadcast [STIS-B] with runway incursion alerting) for providing sufficient situation awareness (SA) and warning to prevent runway incursion accidents.
- Assessment of the performance of aircraft-based runway incursion alerting systems for providing sufficient SA and warning to prevent runway incursion accidents through:
  - STIS-B alerting from airport surface infrastructure
  - Automatic Dependent Surveillance-Broadcast (ADS-B) aircraft to aircraft data link
- Validation of system performance data against evolving RTCA standards for data links, Local/Wide Area Augmentation Systems (LAAS/WAAS), surveillance, and database.

Analysis of the above system objectives was performed by NASA and a variety of contractors including Trios Associates, Inc. Trios' role was to analyze portions of the ground and broadcast systems. Ground system analysis included surveillance coverage, fusion tracker and support sensor update rates, fusion tracker performance, and ground surveillance system position accuracy. Analysis for the Surface Traffic Information Systems-Broadcast (STIS-B) data link include broadcast coverage, broadcast update rate, and system latencies. Much of the analysis performed by Trios was facilitated by Trios' Fusion Algorithm Analysis Tool (FAAT). Portions of these analysis topics are included herein.

RIPS Systems Overview

The Trios-relevant portions of the DFW surveillance system as it was configured during October 2000 testing are illustrated in the block diagram of Figure 1. The individual blocks represent hardware systems that were situated on the ground at the DFW airport. The blocks contained in the large outlined box represent equipment installed on the NASA test aircraft, a Boeing 757 (a.k.a. ARIES). Air-ground downlink communication was established via the 1090 MHz downlink channel currently used by Mode Select (Mode S) and Air Traffic Control Radar Beacon System (ATCRBS). Uplink communications from the Ground Broadcast Transceiver (GBT)

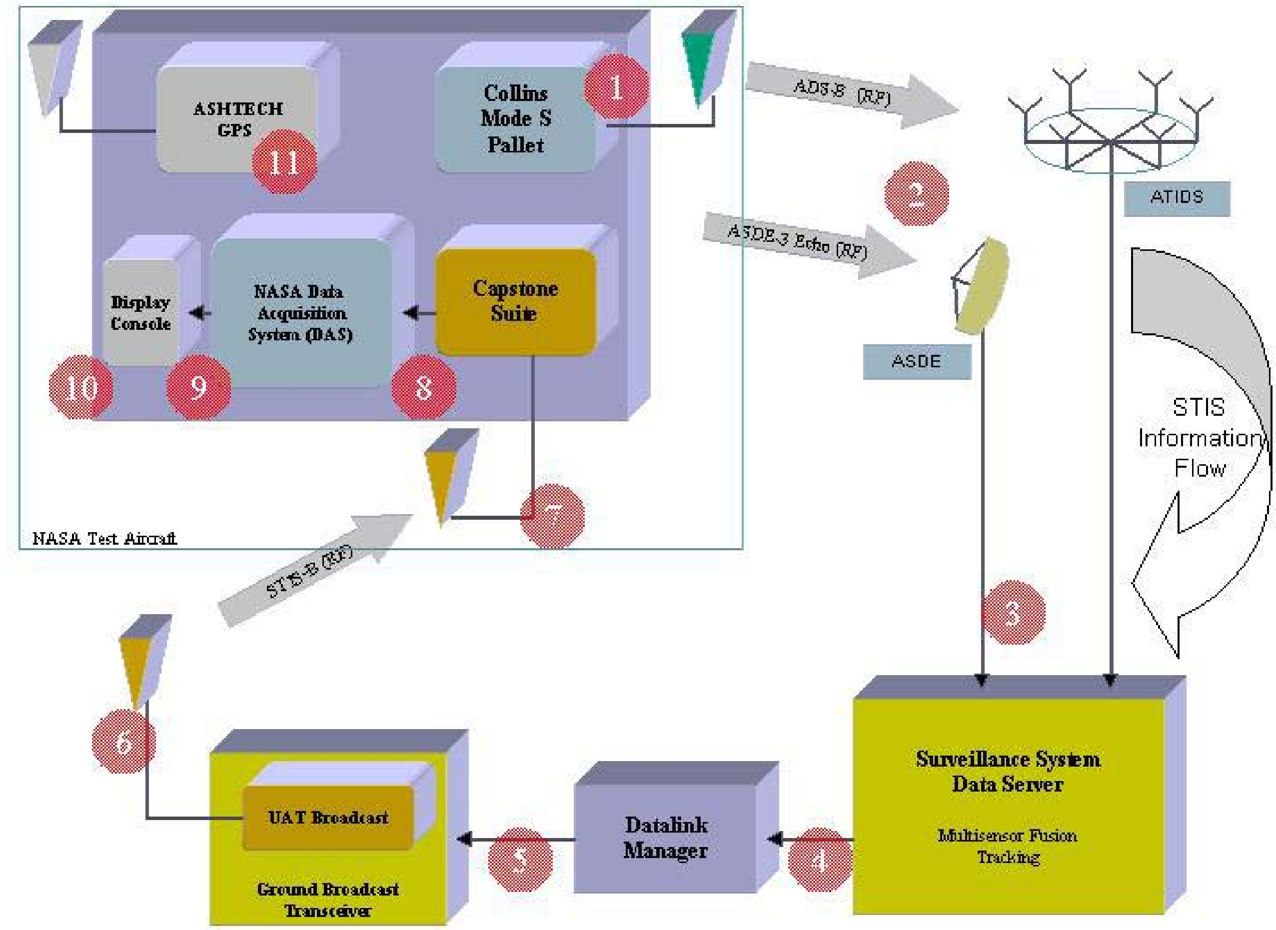

Figure 1; DFW October 2000 Surveillance and Broadcast System Block Diagram

are facilitated via the United Parcel Service – Aviation Technology (UPS-AT) Universal Access Transceiver (UAT). All other communication links were via hardwired connections.

The information flow through the system occurred as indicated by the numbers 1 through 11 shown in the block diagram. A summary of the information flow is presented here.

1) Aircraft broadcasts its position, heading, aircraft ID, and other pertinent information via the Automatic Dependent Surveillance – Broadcast (ADS-B) protocol over the 1090 MHz downlink.
2) The ADS-B message is received and decoded by the Airport Target Identification System (ATIDS). Simultaneously, ASDE-3 radar processes echoes from grounded vehicles.
3) The ATIDS system tracks the aircraft through successive position reports, and passes relevant information via track reports to the Surveillance System Data Server (SSDS). ASDE-3 radar transmits target position information to the SSDS.
4) The SSDS fuses the ATIDS target information with ASDE radar reports and tracks the vehicle. SSDS track reports are updated at about a 3 Hz rate. Every second, the SSDS system forwards track information for targets being tracked to the Datalink Manager (DLM).
5) The DLM converts the STIS-B message to the format used by the Ground Broadcast

Transceiver (GBT) portion of the UAT system and passes the signal to the GBT.
6) The GBT uplinks the STIS-B information to the aircraft via the UAT broadcast system.
7) The STIS-B signal is received by the airborne portion of the UAT system.
8) The received STIS-B signal is transferred to the onboard data acquisition system (DAS), processed, and prepared for display for airline pilot observation.
9) The DAS logs the received STIS-B messages for offline analysis.
10) The on-board displays provide traffic information and situational awareness for pilots whose aircraft are equipped with the STIS-B system.
11) The on-board GPS receiver information is sent to the DAS and logged so that a record of precise aircraft position is recorded with each received STIS-B report. In addition, a separate log of aircraft position and time of position is logged by the Ashtech system, differentially corrected offline, and used as the truth source for position accuracy processing.

Data collection was conducted during two types of airport traffic. First, data were taken during daytime periods when traffic levels were fairly heavy. Analysis of surveillance and alerting systems for typically heavy traffic loading periods was facilitated at this time. Data collection periods requiring test runs of the transponder-equipped test van and the STIS-B equipped NASA ARIES test aircraft were performed during early morning hours when there was little potential for interruption of normally light airport traffic.

The remainder of this Section describes each component of the surveillance system in more detail.

Ground System

Airport Target Identification System

The Airport Target Identification System (ATIDS) is a multilateration system designed to track and provide cooperative identification of aircraft in the coverage volume of the airport surface. ADS-B-equipped aircraft are tracked using the squitters periodically transmitted from the aircraft. Mode S and ATCRBS transponder equipped aircraft are tracked utilizing roll call and "whisper-shout" sequences to elicit transmissions. Replies from ADS-B, Mode S and ATCRBS-equipped aircraft are then received by from three to six ATIDS receiver/transmitter units (RU) located around the east surface of DFW. Time difference of arrival (TDOA) information (multilateration) is used on the receptions to produce position reports.

Additionally, the ADS-B transmissions contain digitally-encoded aircraft status information, including GPS-reported position. The position reports generated through multilateration along with the GPS position information are passed on to the SSDS via the RIRP DFW system local area network (LAN) for inclusion in a fusion track solution.

Airport Surface Detection Equipment

The ASDE-3 system is an advanced primary digital radar that superimposes radar images of all moving airplanes and vehicles over a map of the airport surface. The ASDE-3 is a Ku-band (15.7 - 16.2 GHz) radar, which is designed specifically for detecting traffic (aircraft or vehicles) on the airport surface. The primary radar maintains a one second update rate and provides support data to the RIRP DFW surveillance server system with raw digitized video.

Surface Surveillance Data Server

The Surface Surveillance Data Server (SSDS, i.e., "Fusion") is a multi-tasking Unix-based platform. The SSDS receives positional and flight plan information from various supporting surveillance systems on the airport surface. SSDS communicates with ATIDS and the Data Link Manager through a LAN connection. Flight Planning Unit (FPU) information is received through a serial connection, and provides flight ID information for landing aircraft. The 10-bit ASDE-3 radar signal is connected directly to the Server's Scan Converter via a built in Radar Input Card. SSDS analysis items under test in this paper include airport surface coverage, track report update rates, track report and information latencies, and overall tracker performance.

Datalink Manager

The Data Link Manager (DLM) is a communication interface which serves as a hub for data traffic between the Ground Broadcast Transceiver (GBT) and the Surface Surveillance Data Server (SSDS).

The Data Link Manager is a PC based Windows application. It automatically senses and configures the system connections and begins handling data traffic when the application is launched. A configuration file is used to define the LAN and RS232 connection parameters. The configuration file also contains parameters to specify the data log file names and geographic filter coordinates.

Ground Broadcast Transceiver

The Ground Broadcast Transceiver (GBT) provides an RF link between the ground system and any aircraft receiving Surface Traffic Information Services – Broadcasts (STIS-B) signals. The GBT is programmed to receive STIS-B reports from the DLM, and broadcast those reports via the UPS-AT's Universal Access Transceiver (UAT). The UAT receiver aboard the NASA test aircraft receives the TIS-B broadcasts and forwards the information to the NASA data acquisition system (DAS).

Airborne System

The following items are part of the STIS-B system aboard the NASA test aircraft.

Capstone Suite

The Capstone Suite is the airborne component of UPS-AT's Universal Access Transceiver (UAT). The Capstone Suite receives RF STIS-B uplinks from the GBT and forwards the information to the NASA data acquisition system (DAS).

NASA Computer and Data Acquisition System

The STIS-B message traffic travels from the UAT receiver to a Versa Module Eurocard (VME) based computer to the flight main software residing in the Onyx computer, and finally to the data acquisition system (DAS). The DAS provides logs of all STIS-B received messages for offline analysis.

Ashtech GPS

The Ashtech GPS system aboard the aircraft serves two purposes. First, Ashtech provides GPS position information to the DAS system that is recorded along with TIS-B reports. Thus, aircraft position is recorded every time the DAS receives a TIS-B report. Second, the Ashtech system provides a separate log of aircraft position at regular 1-second updates. Each recorded report is time-stamped with a clock that is synchronized with the ground-based systems. This synchronized log of GPS data is processed offline to provide differentially corrected GPS position and time information that is used as a truth source for position accuracy analysis.

Ground Systems Analysis

The DFW ground system surveillance analysis items include Coverage, Update Rate for each ground-based system, and Fusion Tracker Performance. Analysis for each is provided in this section.

Ground Surveillance Coverage

The method used to illustrate ground surveillance coverage is to plot the positions of system detections through a period of airport traffic. Plots are given for each of ASDE-3 radar and ATIDS systems. No plot of Fusion coverage is provided, as no repeated holes in Fusion coverage are evident in the data.

ASDE Surface Coverage

Coverage characteristics for the Primagraphics ASDE processor are shown in Figure 2. It is clear that there are gaps in coverage, as pinpointed by the callout box in the figure. Coverage gaps are

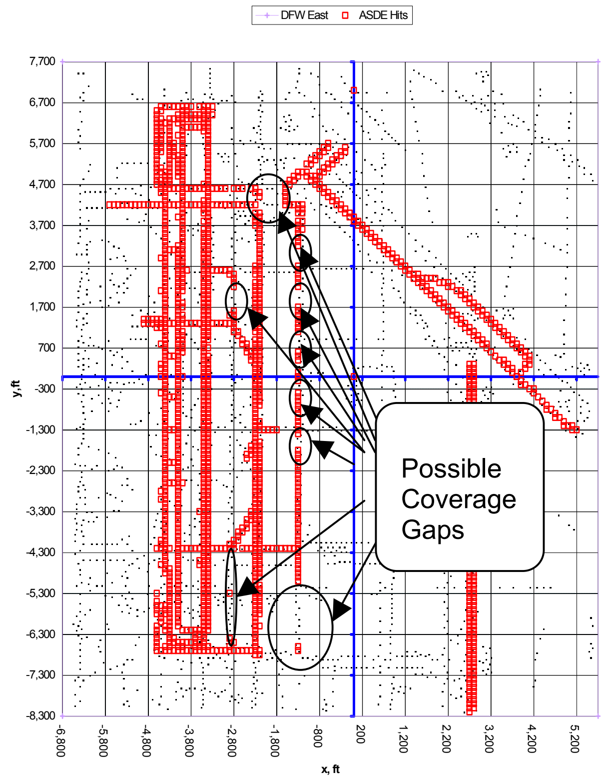

Figure 2; ASDE Surface Coverage

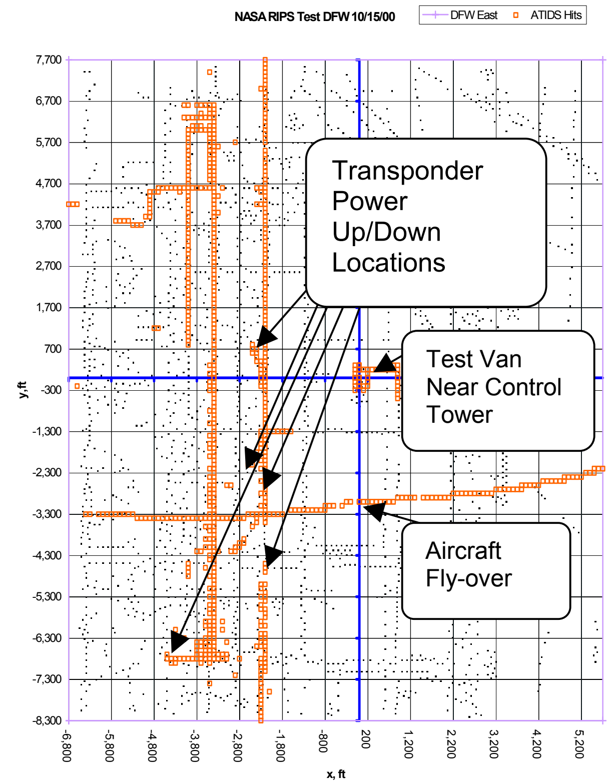

Figure 3; ATIDS Surveillance Coverage

apparent along Taxiway P, Taxiway ER, Taxiway Y & Z between N and 17C, Taxiway M between ER and A-B and between EK and EJ. Gaps in coverage for the ASDE-3 radar could be caused by a number of factors, including deliberate cutouts in the ASDE acquisition map to mitigate false tracks from static clutter, shadowing by obstacles such as hangars and other physical structures on the airport surface, multipath from such obstacles and from the airport surface itself, or poor aspect angle between the radar and the target. Previous coverage tests performed for ASDE-3 at DFW corroborate the findings shown here [3].

ATIDS Surveillance Coverage

ATIDS coverage apparently is not complete also, as shown in Figure 3, with coverage gaps perhaps caused by aircraft de-energizing their transponders on landing, or not energizing them until on the runway prior to takeoff. Previous ATIDS coverage tests at DFW conducted with an instrumented test van indicated that ATIDS coverage showed no apparent gaps over the SSDS surveillance region and runway extensions [4]. The apparent weakness in ATIDS coverage is its dependence on aircraft transponders being on.

SSDS (Fusion) Surface Coverage

The Fusion ground surveillance system showed no apparent gaps in coverage for the NASA test aircraft, illustrating the tremendous benefit of fusing ASDE and ATIDS information.

Fusion Altitude Coverage

Tracking of ground vehicles by the SSDS system is facilitated through sensor support from ASDE-3 radar, and from ATIDS via multilateration, ADS-B, Mode S Extended Squitter, and Mode C reports. ASDE-3 radar provides target position information solely for aircraft on the ground. The ATIDS information, however, includes data from aircraft on approach, data from aircraft on the ground, and data from aircraft either passing over the airport or in holding patterns. Thus, the SSDS system could be currently processing data for targets that are airborne and not presenting a threat to ground traffic. The SSDS processing load and alert system could be relieved of the burden of processing some airborne data if reliable target altitude information could be included in the data being processed. Thus, we provide a look at the quality of altitude information being provided to SSDS via ATIDS from the Mode S squitter, ADS-B, Mode C, and 3D multilateration reports.

Since traffic at DFW approaches primarily from the north and south, a plot of track altitude vs. northing position for all van and ARIES fusion tracks over the total test period provides a first glimpse at the distribution of altitude data available to the SSDS system. An altitude distribution plot for raw altitude information provided to the server is illustrated in Figure 4. Not shown in this figure are many spurious altitude plots, some exceeding 30000 feet and others having large negative values. This plot does show, however, that there are two primary “ground” levels reported, roughly 500 feet and –200 feet. Note also the lines tracing approach and take-off altitude contours that appear to touch down well beyond the runway end.

This collection of altitude reporting anomalies provides a strong indication that altitude information being fed to the SSDS system may be far too unreliable at this time to contribute consistently to runway incursion prevention safety logic.

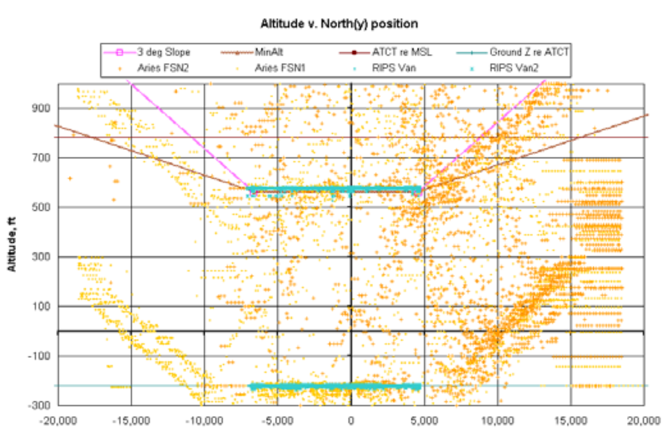

Figure 4; SSDS Altitude Coverage Plot

Update Rate

The track report update rate is a measure in Hertz (Hz) of the average number of track reports per second provided by each system (ASDE, ATIDS, and Fusion) over the test period. Update rate is calculated though the following procedure:

1) Extract message timestamps for selected tracks (ASDE, ATIDS, and Fusion) position reports.
2) Calculate time difference of message time for each pair of consecutive reports in a track.
3) Average those differences.
4) Average the update time interval averages over all tracks selected and reciprocate to get average update rate.

Update rate statistics for ASDE, ATIDS, and SSDS tracks are provided in Table 1 for selected tracks. Statistics for update rate were generated using the Trios FAAT tool. The maximum update rate of 69.4 Hz for ATIDS was verified via manual examination of the data logs as ATIDS on occasion provided updates for the same target to SSDS in bursts [4].

Table 1; Update Rate Statistics

System	Minimum Update Rate (Hz)	Maximum Update Rate (Hz)	Average Update Rate (Hz)	Number of Reports
ASDE	.99	1.6	1.08	144
ATIDS	.17	69.4	2.01	354
SSDS	2.7	5.87	3.01	272

Fusion Tracker Performance

Fusion tracker performance measures include

1) Track Initiation (time to establish track)
2) Target Identification (time to establish ID)
3) Consistency (split, switch, merge)
4) Fragmentation
5) Multisensor Benefits (ID Persistence, Track Persistence).

Track Initiation (Time to Establish Track)

Time to establish track under each of ASDE and ATIDS support is calculated through the time difference between the initial target report from a particular sensor for a particular target and Fusion's first track report. Chosen targets were initiated under support from either ASDE or ATIDS alone, not dual support. Time to establish (TTE) track statistics are presented in Table 2.

Note that ATIDS support provided track establishment on the average in about 1.75 seconds, while ASDE track establishment time was well over three seconds. Both of these values are reasonable since Fusion requires three reports to initiate a track, and ATIDS updates every 0.5 seconds, while ASDE updates occur once per second.

Table 2; Time to Establish Track

Supporting Sensor	Mimimum TTE (sec)	Maximum TTE (sec)	Average TTE (sec)	Total Reports
ASDE	2.52	6.84	3.32	106
ATIDS	0.18	9.35	1.75	108

Target Identification (Time to Establish ID)

Time to establish (TTE) track identification is computed by comparing the time that ID is first provided to the Fusion system and the time that the Fusion system first displays ID. Time to establish target identification statistics are presented in Table 3 for ATIDS only, as the ASDE system requires correlation of landing targets with reports from the Flight Planning Unit to provide target ID to the Fusion (SSDS) system. The average time to establish track ID based on information provided by ATIDS as shown in the table, is 1.5 seconds.

Table 3; Time to Establish Track ID

System	Minimum TTE (sec)	Maximum TTE (sec)	Average TTE (sec)	Number of Reports
ATIDS	0.02	9.35	1.50	105

Track Split, Swap, Merge

Track Splits

A Fusion track split is defined as Fusion's splitting of a single target track into two separate tracks. Splits usually occur when one aircraft or surface vehicle is detected by the ASDE-3 radar subsystem as two or more resolvable plot reports resulting in individual system tracks, or when a fusion track is supported by both ASDE and ATIDS, and the ASDE and ATIDS tracks diverge somewhat. The two-hour period of push data covering roughly 3 – 5 pm the afternoon of October 20, 2000 showed no track splits.

Sensor Track Swaps and Merges

A track swap occurs when track updates of kinematic or identification data from two targets are each erroneously associated with another target. Similarly, a merged track occurs when two or more targets are processed as a single track.

Over a two-hour period of high traffic "push" data, two track swaps and three track merges were found using Trios' FAAT tool. While this tool is useful in identifying such anomalies, and facilitates repeated and slow-motion playback of the tracks in question, analysis of this information in conjunction with recordings of the actual ASDE-3 video is generally required to fully diagnose the cause of these anomalies. Such recordings were not made in conjunction with this test event. During actual test periods, however, when underlying ASDE video can be seen in conjunction with the sensor and fusion tracks, most swap and merge conditions can be seen as attributable to video returns that are not processed by the ASDE tracker where real targets exist.

The ASDE tracker at DFW limits the number of targets within fixed acquisition and tracking zones that are defined by system maps. Only one ASDE track is allowed to exist in any such zone at a time. The DFW areas in which aircraft are staged for takeoff are comprised of several acquisition zones, but at times aircraft are stacked for takeoff two and three abreast, resulting in a number of untracked ASDE targets in these areas. As a pilot is cleared for takeoff, the aircraft transponder is typically activated, allowing ATIDS tracking of the target. If the aircraft picked up by ATIDS happens to be one with no corresponding ASDE track, the fusion algorithm looks for the nearest ASDE "neighbor" with which to correlate the new ATIDS track. This phenomenon occasionally results in initial miscorrelations in the staging area.

As the aircraft that has been cleared for takeoff begins to roll, it separates from the incorrectly correlated ASDE track, and eventually breaks the original correlation. Depending on whether or not a second ASDE track has been formed where there had been none before, this can result in either swap or merge conditions.

Track Fragmentation

Track fragmentation refers to Fusion track segments that either are initiated or terminated in areas where initiation and termination should not occur. For this analysis, such an area is designated a Safe Area. Vehicles entering this Safe Area must do so either from the terminal (departures) or from the runway area (arrivals). Ideally, tracks should initiate and terminate only in terminal and runway areas, and not within the Safe Area.

Because neither of the Fusion supporting sensor systems (ASDE and ATIDS) provides perfect coverage, there are instances when tracks do initiate and terminate in the Safe Area. ASDE support has inconsistencies due to preprogrammed surface blackouts at locations where clutter is known to be a significant problem. The primary deficiency in ATIDS coverage is that pilots are not required to maintain the active state in their beacon transponders throughout the aircraft's presence in the airport surveillance region, resulting in ATIDS tracks initiating and terminating with sporadic transponder power up/down.

Given the problems associated with ASDE and ATIDS support, Fusion track fragmentation is expected to be a significant problem in the surveillance systems. Indeed, the statistics support that expectation, as shown in Figure 5. A *full* track is a Fusion track that starts and stops in expected areas, not in the Safe Area. A track *head* is a track that apparently initiated properly, but terminated within the Safe Area. A track *middle* is a track fragment that initiated and terminated within the Safe Area. A track *tail* is a fragment that initiated

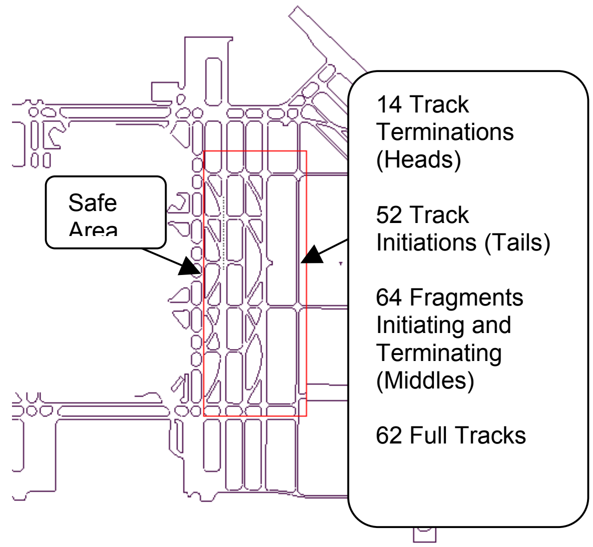

Figure 5; Track Fragmentation

within the Safe Area, but terminated in an expected termination area. In ideal systems, 100% of the track segments would be complete (full) tracks, resulting in no heads, tails or middles. Because ATIDS and ASDE are far from ideal, the Fusion system must create fragmented tracks.

ID Persistence

While the Fusion system depends on its support sensors for quality data, Fusion does provide benefits that neither support sensor can provide individually. One such benefit is ID Persistence. ID Persistence is a measure of the time that Fusion provides track ID beyond the time that Fusion receives ID information from supporting sensors. For instance, Fusion may be tracking an aircraft with support from both ASDE and ATIDS. Should the beacon transponder in the aircraft be powered down, ATIDS would no longer be able to track the aircraft, nor would it be able to provide ID to Fusion. Fusion, however, can typically maintain ID on the track for as long as ASDE continues support. ID persistence for the data set analyzed showed that Fusion was able to maintain ID on tracks 11% longer than ID was being provided by ATIDS, on the average.

Position Accuracy

The ability of the SSDS Fusion system to perform surveillance and safety/alerting functions rests heavily on its ability to provide accurate target position estimates. If the Fusion system cannot determine the location of the targets under surveillance with accuracy and consistency, then the alerting and safety logic can not be expected to perform properly all of the time.

Position accuracy is calculated through comparison of system track reports to the truth position of the NASA test aircraft. The truth position is recorded by the Ashtech GPS system aboard the aircraft and differentially corrected offline. System position reports are given valid-time stamps which allow synchronization with the Ashtech GPS data. Ashtech GPS data are also recorded with a timestamp from a clock that is synchronized with the ground systems clock.

Position accuracy analysis was performed for the test aircraft during taxiing and stationary ground trajectories, and for one airborne test run. Results indicated that the Fusion system leaned heavily on ASDE position information, even though ATIDS position information was typically more accurate and less noisy than ASDE information. This should be qualified by noting that ATIDS reports, whether from multilateration or ADS-B/GPS, provide an estimate of the aircraft's transponder location, which typically is not coincident with the aircraft's image center as observed by conventional radar. This alone introduces some degree of variable bias between ASDE and ATIDS reports as a target maneuvers and changes its orientation on the airport surface.

Statistics for the four grounded test runs and the airborne run are shown in Table 4. Note that in the four grounded test cases, ATIDS position information is statistically far superior to both ASDE and Fusion information. To some degree, however, this is to be expected as the GPS transponder used to record "truth" data is very near the transponder antenna being tracked by ATIDS, and not necessarily at the aircraft's image center. For most commercial aircraft, the difference between transponder location and the aircraft's image center exceeds the position errors reported in the table, which could explain, in part, the discrepancy between ASDE and ATIDS position biases. However, the data analyzed for the May, 2000 data collection at DFW indicated similar disparities in position bias when the vehicle being tracked was the test van, for which transponder antenna and vehicle image center differ by not more than a few feet [3]. It can be concluded, however, that many of the tracking anomalies identified in the detailed analysis of the DFW surveillance systems can be attributed to the sometimes large disagreement in target position between the ATIDS and ASDE systems, no matter what the cause of the disagreement happens to be.

Table 4; Surveillance Systems Position Accuracy

Test Run	Surveillance System	Average Easting Error (ft)	Average Northing Error (ft)	Std Dev Easting (ft)	Std Dev Northing (ft)	Number of Data Points
East Run (20-40 fps)	ASDE	11.7	27.9	23.0	2.2	51
	ATIDS	3.9	-1.1	2.5	.0	156
	Fusion	11.1	30.0	20.0	1.1	153
North Run (20-40 fps)	ASDE	7.0	48.4	10.4	6.0	119
	ATIDS	-1.8	-2.7	4.0	.8	369
	Fusion	7.4	48.3	10.1	0.7	353
Stationary (< 2 fps)	ASDE	27.5	23.8	0.1	0.2	178
	ATIDS	-3.2	-9.3	0.5	0.5	558
	Fusion	26.2	23.6	0.7	0.0	530
South Run (20-40 fps)	ASDE	27.9	-32.6	5.8	0.2	60
	ATIDS	1.5	-5.3	2.7	2.7	178
	Fusion	25.2	-28.8	10.1	1.9	176
Airborne Run (~200 fps)	ATIDS	0.7	-57.7	20.4	9.8	384
	Fusion	7.2	-27.7	27.3	3.6	279

Airborne Systems

Analysis for the airborne portion of the STIS-B system includes broadcast coverage, STIS-B update rate, and system latency.

Coverage

Coverage for the airborne portion of the STIS-B system is defined as the geographic region over which STIS-B updates may be received by properly equipped aircraft. For the DFW October 2000 data collection period, coverage was determined by plotting the NASA test vehicle airborne position at the times it had received an STIS-B update from the Ground Broadcast Transceiver (GBT). Since the aircraft path was confined to a very restricted flight corridor, much of the potential coverage geography was untested. However, plots of the aircraft position during STIS broadcast reveal that while there were a few unexplainable breaks in coverage, there were no geographic regions which were consistently unreachable.

Update Rate

The update rate for tracks reported via the STIS-B system is calculated by dividing the total number of track reports over a time period for a specific track by that time period in seconds. The result is average update rate in Hz. That process was repeated for two tracks reported during October 19, 2000 testing – one track for the test van and one track for the NASA aircraft. Update rate analysis indicated that STIS-B updates were received once per second.

Table 5; STIS-B Update Rate

Update Rate Statistic	Test Van Track	Test Aircraft Track
Average (Hz)	1.01	1.01
Std Dev (Hz)	0.08	0.08
Total Reports	359	186

System Latency

A key characteristic in the Surface Traffic Information Services – Broadcast (STIS-B) system is the time delay between the report of the position of a vehicle under surveillance to the ground surveillance system, and the time that that position is received by the broadcast audience. Latency analysis attempts to provide statistics that illustrate that time delay.

A fundamental limitation in the commercial off-the-shelf (COTS) systems collecting data at DFW in October 2000 prevented an exact analysis of latency in all of the system links. Latency analysis requires that messages whose latency through the system is to be calculated be labeled as they arrive into the ground system. These "tracer" messages must then be carried through the system, accompanying any information for which the messages were used. For instance, the ADS-B messages received and processed by the ATIDS system contain position information for the vehicle initiating the ADS-B message. That position information is used by the ATIDS and SSDS systems to generate track reports based on the ADS-B position information. Because COTS equipment was used in most cases, however, extra data recording capabilities were not generally available, so these "tracer" signals were not available in the DFW systems. Therefore, true latency statistics could not be calculated.

Since signal latency could not be calculated, a variation of signal latency is defined here, called *information* latency. Information latency provides a comparison of a target's position information at the time it is reported in a particular system component to the target's true position. Inherent in this comparison is the time lag between the true position and the time it takes to get that position information to the STIS-B component in question. The position difference between GPS truth and reported position is correlated largely with target speed, so information latency is performed for the test aircraft during airborne flight segments.

Information latency analysis provides an estimate of the information time lag by delaying the time of the truth source until the calculated average radial position error between the logged position information and the delayed truth source is minimized. For instance, we may find that the position of the aircraft as recorded in the DAS log files matches GPS truth position best for GPS information that is 2.8 seconds old. This finding would yield an information latency value of 2.8 seconds in the DAS.

The process of deriving information latency through reduction of the position error through truth-source time delay is illustrated in Figure 6 and Figure 7. Figure 6 shows the DAS-reported Y-coordinate for the NASA test aircraft along with the GPS-recorded aircraft truth position during a southward flight leg of the test aircraft. The line segments connecting DAS and truth-source data icons illustrate the large Y-coordinate position bias, up to 1000 feet for some samples. Figure 7 illustrates the same track segment compared to the truth source when the truth source is delayed 2.8 seconds. Notice that the *y*-coordinate position bias has been nearly eliminated by the delay introduced into the truth source. It is this truth source delay that provides a measure of information latency.

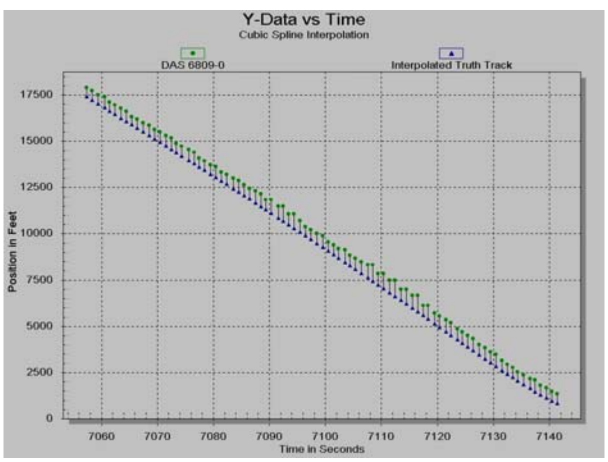

Figure 6; DAS Test Aircraft Test Position vs. Truth (Northing Coordinate) – No Truth Delay

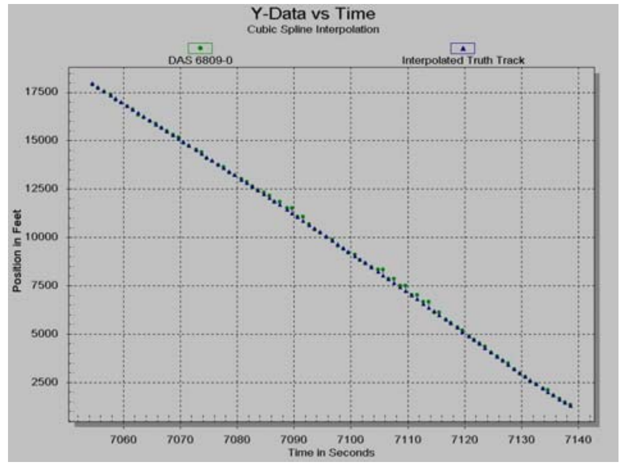

Figure 7; DAS Test Aircraft Test Position vs. Truth (Northing Coordinate) – 2.8 s Truth Delay

Information latency is calculated in the following way. The average radial position error for position estimates of a given target is given as a function of truth source time delay, τ, as

$$\bar{\varepsilon}(\tau) = \frac{1}{n}\sum_{k=1}^{n}\sqrt{\varepsilon_{x_k}(\tau)^2 + \varepsilon_{y_k}(\tau)^2}\ , \tag{1}$$

where n is the number of position measurements of the target provided, and the x and y error components of the k^{th} target position measurement, $\varepsilon_{xk}(\tau)$ and $\varepsilon_{yk}(\tau)$ are given by

$$\varepsilon_{x_k}(\tau) = x_{D_k} - x_{T_k}(\tau)\,, \tag{2}$$

and

$$\varepsilon_{y_k}(\tau) = y_{D_k} - y_{T_k}(\tau)\ . \tag{3}$$

In equations (2) and (3), (x_{Dk}, y_{Dk}) represent the coordinates of the k^{th} measurement, and ($x_{Tk}(\tau)$, $y_{Tk}(\tau)$) represent the coordinates of the GPS truth source τ seconds before the time of the k^{th} position estimate. Information latency is the value of τ that minimizes $\bar{\varepsilon}(\tau)$ in equation (1) for the data points in a track segment as reported in a particular system component.

Information latency values at various locations within the STIS-B system are presented in Table 6. The information latency values indicate, for

Table 6; Information Latency

System	Calculated Information Latency (ms)	Component to Component Information Latency (ms)
ATIDS (ADS-B)	300	300
ATIDS Track	240	-60
Fusion Track	50	-190
DLM Input	90	40
DLM Output	920	830
DAS Output	2830	1910

instance, that the information provided to ATIDS via ADS-B signals (as recorded by the SSDS system) most accurately represented the true position of the aircraft 300 ms, or 0.30 seconds ago. Note that the ATIDS and Fusion trackers actually reduce information latency. That is, position information out of the ATIDS tracker is apparently 60 ms more timely than the information into the tracker, and Fusion output is about 190 ms more timely than input information. Information latency improvements are expected in those systems since they predict target position. Ideal trackers would provide systems with zero information latency.

Of special note is the overall system latency of 2.83 seconds at the output of the airborne DAS system. This means that the position information provided to airline pilots was most accurate 2.83 seconds ago.

Caution should be used in interpreting information latency. First, selecting the value of τ that minimizes the quantity in equation (1) assumes that the position bias when there is no latency is zero. Such is generally not the case, as can be seen from the position error results in Table 4. Second, information latency was calculated through averaging information latency over several data sets. Presentation of the information latency values calculated for each data set analyzed is beyond the allotted space given to this paper, but do note that there was significant variance to the individual latency values derived, indicating that much larger data samples would need to be analyzed in order to produce latency values with reasonably sized confidence intervals.

Conclusions and Recommendations

The RIPS system installed at DFW airport and tested during October, 2000, is a major step in the goal of making automated traffic surveillance and situational awareness information available to air traffic controllers, airline pilots, and other airport personnel. Results of the tests conducted indicate progress towards that goal, but also indicate some issues that need to be addressed before a safety and alerting system can be successfully implemented.

The heart of a successful surveillance and safety / alerting system is reporting target positions accurately and in a timely fashion. The RIPS system will need to make strides in reporting timeliness, and the SSDS and supporting sensors will need to improve in areas such as position accuracy and bias if safety and alerting algorithms are going to be accepted for general use by pilots and ATC personnel.

A more complete discussion of system analysis and related concerns is presented in the complete analysis report [4].

References

[1] Levin, Alan, "Runway Safety Problem Persists," USATODAY.com, June 20, 2001

[2] Levin, Alan, "Runway Incidents Called a Top Hazard," USATODAY.com, May 16, 2001

[3] "Runway Incursion Reduction Program-Dallas - Fort Worth Formal Evaluation Report," Trios Associates, Inc., December 21, 2000.

[4] "Dallas-Fort Worth RIPS Performance Analysis: Ground-Based Surveillance Systems; Surface Traffic Information Systems Data Link," Trios Associates, Inc., May 31, 2000.